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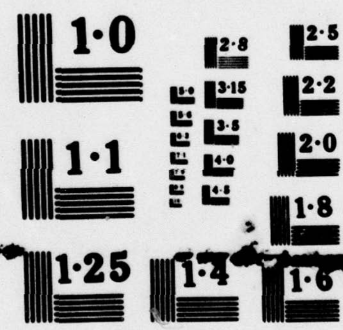
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LEVEL II

Short-Range Forecasting Through Extrapolation of Satellite Imagery Patterns
Part I: Motion Vector Techniques

H. STUART MUENCH
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26 April 1979

METEOROLOGY DIVISION PROJECT 6670
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AIR FORCE SYSTEMS COMMAND, USAF

This report has been reviewed by the ESD Information Office (OI) and is releasable to the National Technical Information Service (NTIS).

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FOR THE COMMANDER

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Chief Scientist

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The advent of the geosynchronous satellite with 1-km resolution has presented meteorologists with the opportunity to routinely track and forecast smaller scale weather phenomena than hitherto was possible. The enormous data rate, however, precludes a completely manual system of data interpretation and forecasting, so to fully utilize this opportunity we must use computers. Following examples set by forecasters using digitized radar data, we are developing techniques to make guidance forecasts through automatic extrapolation of satellite imagery. Candidate techniques for extracting motion vectors

→ next page

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from satellite imagery have been selected and programmed. This report describes the techniques and presents results of a preliminary test using simulated motions of selected satellite video images.

Contents

Illustrations

Tables

Short-Range Forecasting Through Extrapolation of Satellite Imagery Patterns

Part 1: Motion Vector Techniques

1. INTRODUCTION

The role of weather satellites in forecasting has been steadily growing over the years. The great advantage of the satellite information over conventional weather data is the scale or resolution. Conventional weather stations report conditions every 100 km or so over land, and every 1000 km over the oceans (and sparsely populated land areas). On the other hand, satellites can make readings down to a resolution of 1 km or less, so they can readily track the small disturbances that are associated with heavy rain, heavy snow, wind squalls, and dense fog, which have always been difficult to forecast. The early polar-orbiting satellites observed many of these small-scale patterns, providing a new perspective to the forecast problem. Their usefulness was limited, however, both because the analog output was difficult to digitize for quantitative studies, and because a satellite would take observations over a given point only once every 12 hr—too infrequent to track small-scale disturbances that usually have lifetimes of 6 hr or less. The current generations of geosynchronous satellites removes these limitations by providing calibrated, digital values of video and IR brightness, repeated at half-hourly intervals (with provision for special observations over limited areas at more frequent intervals). Thus the geosynchronous data are very amenable for the development of subjective and objective forecasting techniques.

(Received for publication 25 April 1979)

There are several ways one can introduce digital satellite information into the short-range forecast process, and the choice depends on such factors as facilities available, type of forecast (for example, route vs terminal), and how quickly results are needed. A primary consideration is that the high spatial and temporal resolutions result in an enormous data-rate from the satellite. In fact, a single GOES satellite in only a few seconds transmits more numbers than are transmitted by all of the conventional weather observers in the world in a 24-hr period. Synoptic meteorologists are quite accustomed to working with many numbers. For example, during a forecast experiment at AFGL[1] a meteorologist made forecasts out to 3 hr using conventional aviation weather data. In preparing for these forecasts, hourly charts were drawn for an area about 500×500 km containing about 50 weather-observing sites.

Altogether, some 600 numbers would go into constructing the patterns of weather elements that were portrayed on each chart, and the preparation and analysis of the chart kept the meteorologist busy. Yet for this same area, the GOES East satellite generates some 600,000 video numbers and 9000 IR temperatures every hour, a rate orders-of-magnitude greater than the forecaster can reasonably assimilate. There is no question that computers must be used to assist the forecaster, either through preparation of "guidance" forecasts or else through extraction of information pertinent to the forecast problem.

Computers have played an important role in forecasting, both through numerically produced forecasts of weather patterns and through statistically produced forecasts of weather conditions. The ever-increasing speed and memory capacity of computers now allows operational forecasts with a resolution of 100 km to be made within a few hours of the data cutoff. But, for the short-range forecasts, we need a resolution of at least 10 km and a speed of 1 hr or less to predict the important mesoscale features. Such a capability would appear to be many years in the future. On the other hand, if we are to use statistical models,[2] we must screen tens or hundreds of thousands of potential predictors, which would require equally large numbers of sample cases to develop reliable equations. This task would likewise over-tax the present generation of computers.

Radar meteorologists also encountered the problem of excessive data rates when digital radar information became obtainable. Several groups[3,4] have demonstrated

1. Hering, W.S., Muench, H.S., and Brown, H.A. (1972) Mesoscale forecasting experiments, Am. Meteor. Soc. Bull. **53**:1180-1183.
2. Reap, R.M., and Foster, D.S. (1977) Automated Prediction of Thunderstorms and Severe Local Storms, NOAA Technical Memorandum NWS TDL-62.
3. Austin, G.L., and Bellon, A. (1974) The use of digital radar in short-term precipitation forecasting, GJRMS. **100**:658-664.
4. Muench, H.S., and Lamkin, W.G. (1976) The Use of Digital Radar in Short-Range Forecasting, AFCRL-TR-76-0173, AD AO33624.

the feasibility of making short-range forecasts for a fixed location directly from high-resolution radar data. The technique involves extracting a motion vector from a series of radar images, then forecasting future radar intensities over a site by extrapolating the patterns into the future using the most recent vector calculation (see Figure 1). Finally, a forecast of the weather condition is made through relationships between weather and radar intensity. The technique assumes that the patterns move consistently enough to establish reliable motions or translations, and that there is a useful correlation between the digital values in the patterns and the weather conditions to be forecast. While the procedure can be done by hand, it can be done quicker and more objectively by a small computer.

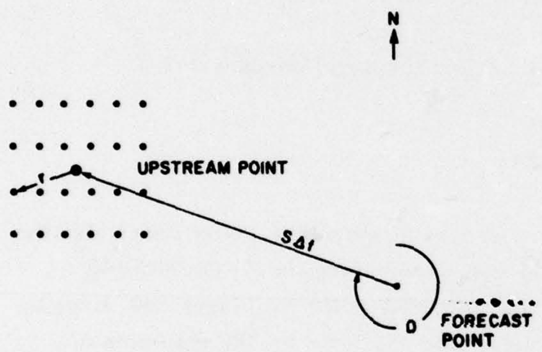

Figure 1. Method of Extracting Forecast Value Given Time and Motion Vector

Since the data rates for the satellite and the radar are similar, it would appear that this approach should be considered for satellite data. Certainly the experience of meteorologists with "film loops" of sequential satellite pictures indicates that the patterns do move with sufficient regularity to make forecasts through extrapolation, at least for large scale patterns. Radar observations have also shown regular motion for small-scale features, but Muench and Brown[5] did note that on occasion varying weather conditions were caused by geographically stationary patterns that oscillated in intensity with time. Fortunately, the technique involves two sequential steps, and if it is not completely successful at first, it should be possible to determine quantitatively whether errors are primarily due to inadequate motion vectors or to inadequate routines for converting satellite measurements to weather conditions.

5. Muench, H.S., and Brown, H.A. (1977) Measurements of Visibility and Radar Reflectivity During Snowstorms in the AFGL Mesonet, AFGL-TR-77-0148 (see p. 29), AD A049258.

To carry out an evaluation of this technique as applied to forecasting from satellite imagery, there are basically five requirements:

- Satellite imagery data from a variety of cases, preferably half-hourly intervals.
- Computer programs of techniques for determining motion vectors.
- A procedure to forecast satellite brightness and IR temperature given the motion vector.
- A procedure to convert brightness and IR temperature to weather parameters.
- A system to evaluate the effectiveness of different motion vector techniques relative to each other and to other short-range forecast techniques.

This report describes progress on this effort through February 1979.

2. COLLECTION OF SATELLITE IMAGERY DATA

Since February 1977, there has been a program to archive GOES East satellite data (visible and IR) at hourly intervals on weekdays, using the AFGL McIDAS* facility. A microprocessor-controlled tape recorder collects images 500 lines by 672 elements of 1-mile-resolution video data† and 125 lines by 168 elements of 4-mile-resolution IR data, for the fixed area of the box within Figure 2. Data are recorded from 0900E to 1600E on weekdays within the constraints of equipment availability. More data would certainly be desirable, but compromises were necessary because of manpower demands in the navigation, scheduling, and the handling of tapes. On selected days, an extra effort was made to collect data at half-hourly intervals. In November 1978 a program in the McIDAS computer began scheduling the microprocessor, and since that time half-hourly images are normally collected from 0800E to 1300E on weekdays. The half-hourly frequency is preferred for determining motion vectors, as the development and decay in the cloud patterns taking place over longer intervals would certainly complicate the task.

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*Man-Computer-Interactive-Data-Access-System.

†Lines 1.4 mi or 2.7 km apart, elements 0.8 mi or 1.5 km apart.

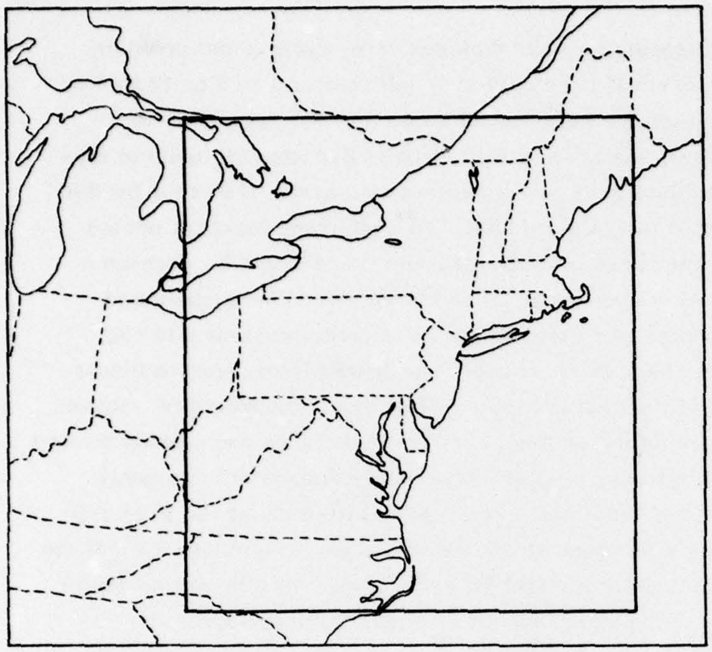


Figure 2. AFGL GOES Data Archive Area (1 mile video, 4 mile IR)

3. MOTION VECTOR TECHNIQUES

A search of the literature revealed several promising motion vector techniques. In fact, some techniques were in operational use in a semiautomatic mode, for using cloud motion to specify winds aloft. To reduce requirements for skilled manpower, we would prefer that the technique be fully automatic. Also, the technique must work with complex cloud systems, not only with small cloud cells or elements. While all of the techniques use arrays of data values separated in time as input, two basically different approaches have been followed. SRI has developed techniques[6,7] that identify individual "clouds" or data "clusters" and match pairs from consecutive arrays to determine the motion. The technique used at NOAA,[8] on the other hand, looks for the highest cross-covariance between arrays that have shifted right, left, up, and down, using fast Fourier transforms of the arrays in the computations to save computer time. The motion vector is computed from the displacement with the highest covariance.

6. Endlich, R. M., Wolf, D. G., Hall, D. J., and Brain, A. G. (1971) The use of pattern recognition technique for determining cloud motions from sequences of satellite photographs, J. of Appl. Meteor. **10**:105-117.

7. Wolf, D. E., Hall, D. J., and Endlich, R. M. (1977) Experiments in automatic cloud tracking using SMS-GOES data, J. of Appl. Meteor. **16**:1219-1230.

8. Leese, J. A., and Novak, C. S. (1971) An automated technique for obtaining cloud motion from geosynchronous satellite data using cross-correlation, J. of Appl. Meteor. **10**:118-132.

Before programming and testing these techniques, the scope of the problem must be better defined. The forecast time period of interest is 0 to 3 hr (0 to 6 hr if feasible). If we are to consider a single station and allow for speeds up to 20 m sec^{-1} (40 kt), we must track patterns out to at least 220 km (120 nmi) in distance. Thus, for the archived data grid, we would need an array 170 rows by 290 elements, with the forecast station in the middle. To double the forecast period would require an area with twice these dimensions, and there might be problems with significant changes in motion vectors at large distances. The documented techniques were for square arrays of considerably smaller dimensions—30×30, 64×64, and 70×70. A square shape is reasonable, as it will likely lead to better compatibility in the accuracy of the eastward and northward components of motion.

The choice of grid size is another problem. If the techniques were programmed for a 240×240 grid (comparable to the 170×290 previously suggested) computer storage problems would arise. If the small arrays are shifted about the 170×290 grid, repeating the computations for each shift, we would get better definition of the motion vector field, but computing time might be excessive. An alternative would be to reduce the resolution by using every eighth or every third point, as the developers of the techniques had in fact done in their applications. An important consideration here is that small-scale features of 1 to 3 grid lengths (2 to 6 km) have lifetimes of only about 20 min,[9] too brief to reliably track with arrays at 30-min intervals. So, the reduced resolution is the most desirable solution.

The first technique to be programmed was based on an SRI report[6] that described their techniques for extracting "brightness centers" from the data arrays and "matching" the centers from successive arrays. The basic input is a 90×90 array of video brightness values, and from this array the program selects every third row and every third element to form a 30×30 array. Next, from these 900 values, the brightest 100 are selected and these are thereafter treated equally, regardless of actual brightness. Then, two passes are made through the list of 100 points to identify and locate "centers". The first step is to locate the center-of-gravity of the 100 points and then compute the average distance* of the points from the center-of-gravity, r_{cg}. The center-of-gravity becomes the first "center" and a circle of 0.5 times r_{cg} is drawn around this first center and all points within are removed (temporarily) from the array. Now, starting with the upper-left of the array, a search is made until the first remaining point is found, and a circle of 1.0 times r_{cg} is drawn. The center-of-gravity of the points within this circle is computed. This becomes

9. Umenhofer, T.A., and Fujita, T.T. (1977) Thunderstorm-associated cloud motions from 5-min SMS pictures, 10th Conference on Severe Local Storms, AMS Preprint Volume, p. 23.

*In computing the average distance, increments of row and column are treated as equal.

center number two, and again the points within the circle are temporarily removed from the array. The process is repeated until all 100 points have become associated with some center, and then removed from the array. Before beginning the next pass, a search is made through the lists of all centers, and those with less than six points are dropped—the points within are permanently removed from the field. This exclusion eliminates small, unreliable features. The second pass begins, and proceeds exactly as the first, except that there may be fewer than 100 points at the start. The result of the procedure is a table of brightness centers, listing the position of each center and the number of associated points. The second of the consecutive arrays is read in, and the procedure is repeated to obtain a second table of brightness centers.

Having obtained the two sets of brightness centers, the next task is to find the best matches and from them compute a representative displacement. The program starts by finding the displacement of center number one (overall center-of-gravity). Then, trial displacements of all combinations of centers from the two sets are calculated, subtracting from each the displacement of center number one. These trial displacements are thus displacements relative to the motion of the overall center-of-gravity. The best matches are assumed to be those with the smallest relative displacements, so matching is performed by searching through the table of trial displacements for the smallest value, removing the pair and working up to the next smallest, and so on until an acceptance threshold is reached. This acceptance level is equivalent to a motion relative to the center-of-gravity of about 10 m sec^{-1}. The average relative displacement of the acceptable centers (in units of row and column increments) is computed, and the components of the displacement of center number one are added. Then, row and column scale factors are applied to produce geographical components of displacements. After dividing by the time difference between satellite images and converting to polar coordinates, we have a motion vector for the cloud pattern.

The program as used in this study does include a few minor departures from the technique described by SRI.[6] From trials, we found that better tracking was obtained by using 0.5 r_{cg} instead of 1.0 r_{cg} for center number one, and 1.0 r_{cg} instead of 0.7 r_{cg} for the other centers. Also, we drop centers with less than six points rather than three, as prescribed by SRI.[6] Finally, we did not program the "splitting" and "lumping" routines, as they were considered optional and were not sufficiently well documented in the journal article[6] to reproduce.

In 1977, the SRI group developed modifications to their technique,[7] both to eliminate some of the "spurious motions" the earlier program would produce on occasion, and to reduce computation execution time. The new technique was put into operation at the Naval Environmental Prediction Research Facility (NEPRF)

at Monterey, CA and a FORTRAN listing of this operational program was provided to us.[10] From this listing, programs to compute motion vectors were written for the AFGL CDC 6600. In this new SRI version, consecutive 70×70 arrays of GOES video count values are used for input, and the first step is to eliminate all but the brightest 6 percent (about 300 points) of the values in each array. Next, a routine joins all continuous points (touching diagonally or along a row or a column) into individual cloud groups. Each group is described by number of points, location of geometric center, average brightness count, and two measures of shape (rms dispersion about center row and column).

Once we have identified and described characteristics of cloud groups in two consecutive arrays, we can start to match cloud groups to obtain pattern displacement. In this new procedure, four scans are made through the table of cloud group data, with successively increasing complexity. Initially, pairs are matched that have displacements closest to a "guess" (a previous displacement or zero displacement for the first pair of satellite images of the day), but not exceeding an acceptance criterion. From the displacements of the acceptable matched pairs, a new "guess" displacement is computed and the procedure is repeated. In the third and fourth scans, the difference between displacement and guess and the differences in brightness and shape parameters are minimized in the matching. At the end we have an optimum pairing of cloud groups, and from the pairs, average row and column displacements are calculated. As with the 1971 version, we then apply scale factors, divide by the time difference, and convert to polar coordinates to obtain a motion vector.

Some changes in the program were necessitated by differences in the hardware configuration between the NEPRF Nova computer and the AFGL CDC 6600. Principle differences found were the "word" size (16 bit vs 60 bit), disc file procedures, some input/output features, and "common" storage. The real-time interactive graphics features were not put into our program, nor were some optional, time-consuming[11] routines such as "SPLIT", "LUMP", and "ISODATA". Certain criteria designed to exclude spurious motions were changed to be compatible with the geographical size of our grid and with the typical cloud motions found in the region of our archived data.

The third technique to be programmed was one that obtains motion vectors through cross correlation, as described by Leese et al.[8] Basically, one takes two consecutive data arrays and methodically shifts one array relative to the other: up, down, right, and left. For each shift, the cross-covariance between the two arrays is computed. One then searches the table of resulting covariances to find the number

10. Nagle, R. (1978) Personal communication.

11. Nagle, R. (Nov. 1979) Personal communication.

of rows and number of columns shifted that produced the highest covariance, and this is assumed to be the cloud displacement. Leese et al[8] noted that while the computing of cross-covariance is time consuming, the procedure is much faster if the arrays are first transformed into the frequency domain through "fast Fourier transform" (fFt).

A very fast and quite flexible fFt cross-covariance routine was written. An increase in speed was achieved by using a working array that had dimensions that are powers of 2, and for our computer the largest practical size is 64 $\times$ 64. However, the actual data array for input must be smaller, so 32 $\times$ 32 arrays were used in this study. The program starts by finding the mean value of the first 32 $\times$ 32 array of satellite video values and then subtracting the mean from each value in the array. Next, the 32 $\times$ 32 array is placed in the center of the 64 $\times$ 64 working array and all the surrounding points (16 in each direction) are set to zero. A fast Fourier transform then transforms the data into the frequency domain. The procedure is repeated for the second of the consecutive satellite images.

Next, cross-covariances are computed for shifts between the arrays, 32 columns right and left, 32 rows up and down. The result is a 64 $\times$ 64 matrix of cross covariances. To get cloud displacement, one can simply search through this matrix and find the displacement with the highest covariance. However, we can obtain better resolution by fitting a quadratic to the covariance data and solving for the position of the maximum (separate calculations are made for row and column). Given this displacement, the program proceeds as in the other techniques to convert to geographical units and to polar coordinates to obtain the motion vector of the cloud system.

There was some concern that using 32 $\times$ 32 arrays with an equivalent grid length of about 15 km (8 nmi) might result in poor resolution in the motion vector, even with the quadratic interpolation. For example, an uncertainty of 5 km in locating the maximum covariance would result in an error of 2 m sec^{-1} for images 1/2 hr apart, which could be 20 percent or more of the actual motion vector. Since the fFt routine is very fast, we simply chose a 64 $\times$ 64 array and made four passes with 32 $\times$ 32 arrays over the area, and averaged the four motion vectors.

An alternative form of the cross-covariance technique was devised by taking advantage of a set of computer instructions that perform binary arithmatic, sometimes referred to as "masking" instructions. If we take some threshold of cloud brightness to represent the edge of a cloud, we can assign a value of one to all the array points with greater (or equal) brightness and a value of zero to all points less bright. Since a CDC 6600 "word" is made up of 60 "bits", we can compact 60 array points into one "word". If we have a second 60-bit word from the next array (30 min later), we can get 60 simultaneous cross-products executing one computer instruction (COMPASS "logical product" or FORTRAN "AND"). As an example for 10 "bits":

t	0001111110
t + 30	<u>0011111000</u>
cross prod.	0001111000 .

A second instruction (COMPASS "population count") will sum all the 1's in the 60-bit word (four, in our example). Common sense suggests that matching of the zeroes is as important as matching the ones, or, the tracking of holes in clouds is as important as tracking clouds. Thus we would also like a "1" to result wherever there were two "0"s. Fortunately, there is again a single instruction that will achieve this result (COMPASS "complement and logical difference"). Thus:

t	0001111110
t + 30	<u>0011111000</u>
cross prod.	1101111101 ,

which gives seven matches.

To use this concept in a program, we start with an initial 60×60 array of video-count values and, using a threshold, convert to sixty 60-bit words. At the second time period we look at an 80×80 array, which will allow up to 10 displacements right, left, up, and down. For each of 400 displacements (20×20), we use the same threshold (a different one could be used if justified by changing solar zenith angle) to construct sixty 60-bit words. The programs then find the total matches (analogous to cross-covariance) between the initial and each of the 400 final arrays. The result is a 20×20 table of total matches. The displacement with the best match is found, and the position of the maximum is refined through interpolation (quadratic fit). Multiplying by scale factors and dividing by time gives a motion vector. To make more complete use of the data, and obtain better resolution, we go through the process for each of three different thresholds (based on a histogram of brightness (frequencies), and the final motion vector is the vector mean of the three.

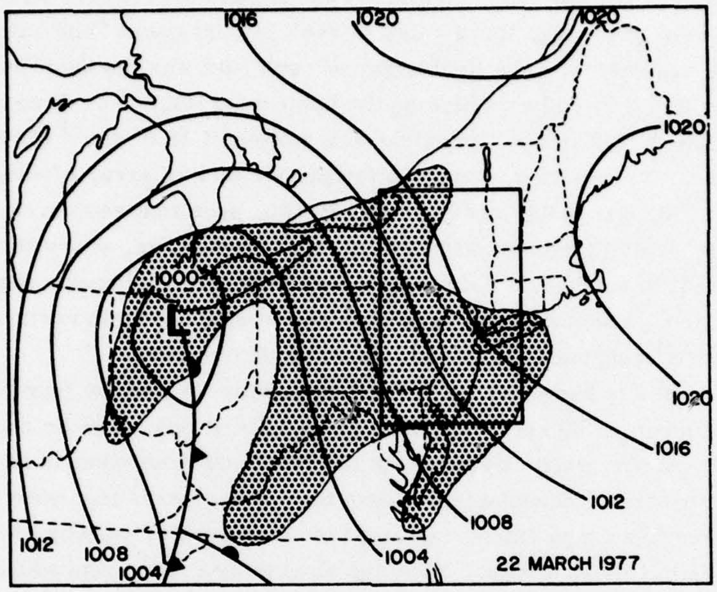
4. TESTING WITH SIMULATED DISPLACEMENTS

A simple, yet effective, test of a motion vector technique is to provide an initial array of satellite imagery data and a second array from the same image only artificially displaced a specified distance. The displacement is known and there can be no complications due to cloud development or changing sun angle, so the technique should be able to reliably compute the displacement. For input data, a single GOES image (either 1500 or 1600 GMT) was extracted from our archived tapes on each of six days in the spring of 1977. A variety of cloud and synoptic weather conditions were represented, as seen in Figures 3a-3f, including widespread clouds with

precipitation, a cold-frontal band, convective cloud band in cold air, and warm-frontal clouds. For each day, three pairs of 240×240 arrays of "one-mile" GOES video data were assembled. The first array of each pair was the basic image, and the second array was formed by displacing the basic image in one of three directions (WNW, NE, or SSE), a distance equivalent to a motion of 15 m sec^{-1} (30 kt) for 30 min. Routines were written to provide the proper size of array of each of the four techniques, 30×30, 70×70, 64×64, and 80×80, such that each array as nearly as possible represented the basic 240×240 array. In one case, every third row and column was taken; in another, a point every 3-1/2 rows and columns, requiring some interpolation. The programs were then run to obtain motion vectors, to see how closely they corresponded to the simulated cloud motions.

As the first results became available, it was apparent that the first three techniques were not performing satisfactorily, and modifications would be necessary. When the cloud patterns were complex, the two SRI techniques were making incorrect matches, apparently because there were too many centers too close together. This problem was to a large extent corrected by applying an 8-row by 16-column linear smoothing to the input data. After the smoothing routine was added, all four programs produced excellent motion vectors when the basic cloud pattern was in the center of the array. Except for the binary covariance technique (No. 4), the techniques performed poorly when much of the cloud mass was on one of the borders. This problem could be avoided in the semi-automatic mode by having an operator at an interactive console move the grid so that the cloud system was in the center at the start of the computation. Clearly, this procedure would not be possible for a fully automatic system, which is one of our goals.

Part of the problem with the SRI programs can be traced to the use of a fixed number of cloud points, 100 in the 1971 SRI program and about 300 in the 1977 version. When a cloud pattern is moving into an array, higher values will appear on the border of the second array than on that of the first, and the cutoff threshold will be higher for the second array than for the first. This means that some centers of cloud groups that might be present in the center of the first array may be below the threshold for the second and thus be dropped. This can then lead to poor matching. A related problem is that the 1971 SRI program relies heavily on the overall center-of-gravity (center number one) and this center will change very little in position, with a fixed number of cloud points, as the pattern moves into the array. It may be feasible to modify these SRI techniques to alleviate this problem, but this has not yet been attempted.



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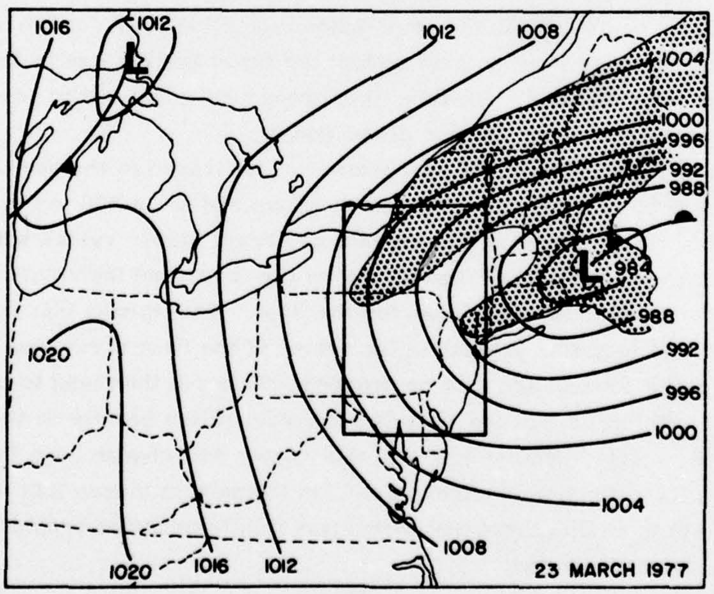
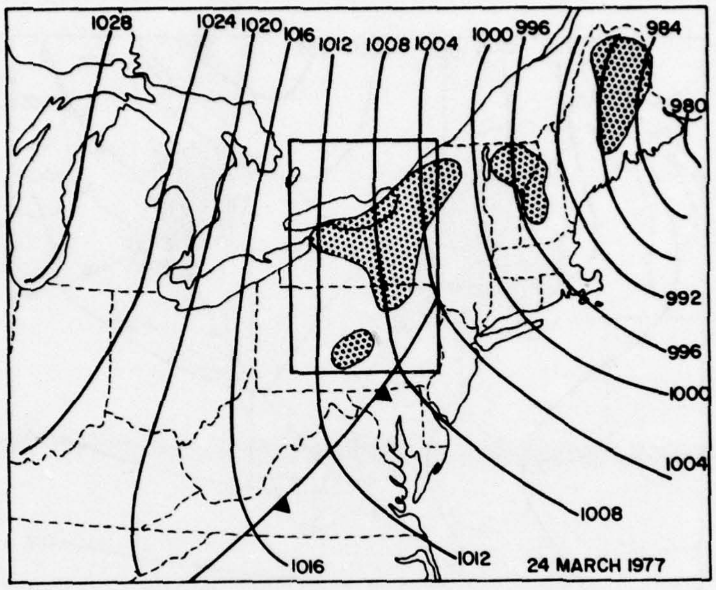


(b)

Figure 3. Surface Weather Maps for Test Cases (1200 GMT); Stippling Represents Precipitation



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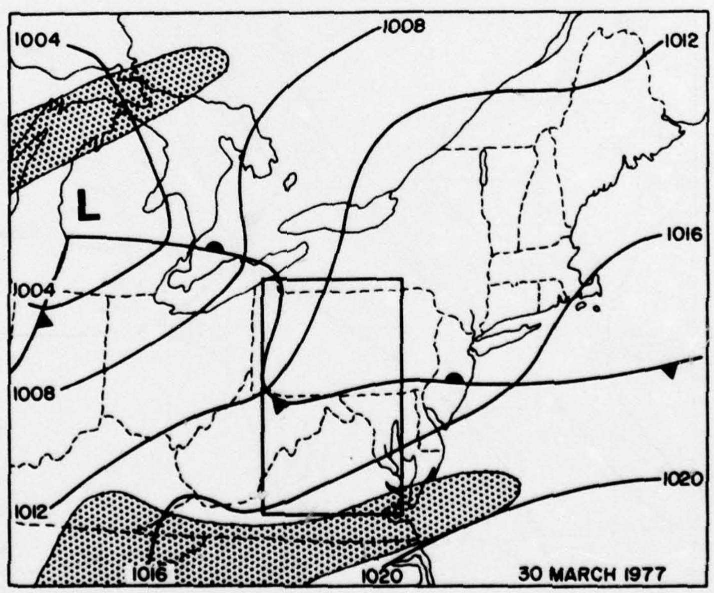
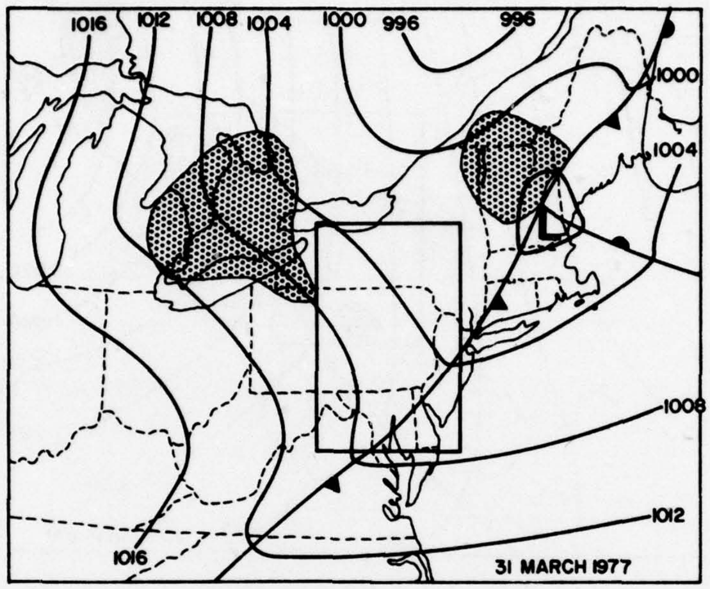


(d)

Figure 3. Surface Weather Maps for Test Cases (1200 GMT); Stippling Represents Precipitation (Cont)



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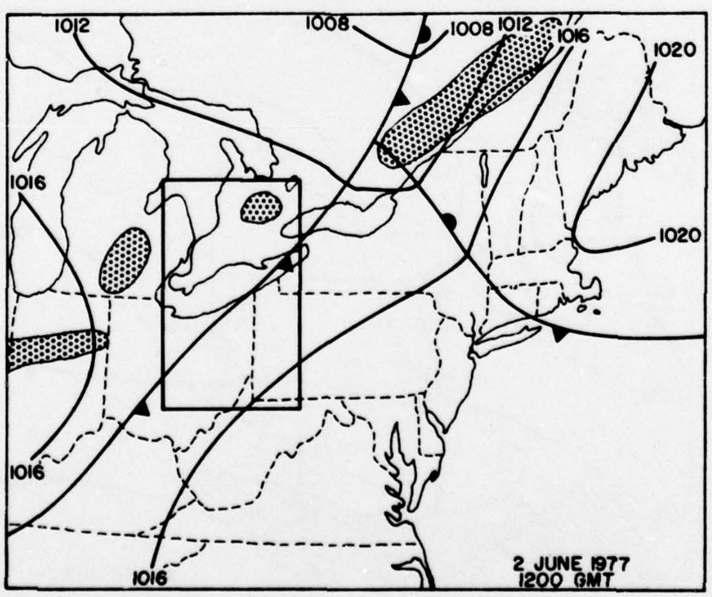

(f)

Figure 3. Surface Weather Maps for Test Cases (1200 GMT); Stippling Represents Precipitation (Cont)

In the case of the fFt cross-covariance program, the problem is related to the zero values placed in the outer 16 points of the 64×64 working array. As the cloud pattern moves into the array, the initial data array will have the highest values on the border, and the following data array will have even higher values on the same border. For zero displacement, the cross products from the border will be large. When the array is shifted, the high values at one border will overlay the zero values outside the border of the other array, and the high values at the border of the second array will overlay lower values of the interior of the first array. There are no cross products anywhere near as large as those of the zero displacement, and the technique fails to produce the proper motion vector. A partial solution was found by computing the average slope from one edge of the 32×32 data array to the opposite edge and subtracting this trend from the data. Two passes are made, across rows and down columns. This transformation has little effect when cloud patterns are in the center of the array and the motion vector technique normally works well, but when patterns are moving across the borders, it lowers the values along the edges.

Once these engineering modifications were made to the motion vector programs, the techniques were tested with the six test cases, producing 18 motion vectors for each technique. The errors representing the differences between artificial displacement and computed displacement are shown in Table 1.

Table 1. Test of Motion Vector Techniques Using Artificial Displacement (18 vectors, simulating 15 m sec^{-1} for 1/2 hr). ϵ_x and ϵ_y are rms errors in 1-mile grid units. Vector error is rms resultant error divided by artificial displacement

	SRI 1971	SRI 1977	fFt Cross Covariance	Binary Cross-Covariance
ϵ_x	± 8.3	± 6.0	± 4.9	± 0.3
ϵ_y	± 3.9	± 3.7	± 3.8	± 1.5
Vector Error	± 59%	± 49%	± 42%	± 10%

On this test, the binary cross-covariance technique was clearly superior to the others. However, this test was not an exhaustive one, and we would like to see how each technique is affected by the cloud growth and decay that occur in actual sequences of images before drawing conclusions. By way of comparison, Muench and Lamkin[4] found errors of from ± 15 to ± 20 percent in automatically tracking precipitation areas, using digitized radar information.

The next test will be a series of 10 to 15 cases, each with a sequence of 3 hr of half-hourly video images. From each image, up to four sections (centered over radiosonde stations) will be extracted. In these tests, the "true" motion vector will not be known, as it was for artificial displacements, and one might consider manually obtaining motion vectors for verification. However, the object is to forecast the brightness values, so the most appropriate verification would be through forecasts of brightness using the motion vectors and spatial extrapolation. At this stage we will also introduce motion vectors based on winds aloft, for comparison purposes. This will not only give a comparison between the effectiveness of each technique, but also an estimate of the overall value of the techniques in forecasting change.

5. SUMMARY AND CONCLUSIONS

The geosynchronous satellite with 1-km video resolution and 30 min image frequency presents meteorologists with an opportunity to forecast small scale weather patterns. The data rate is too great, however, to allow processing by hand, and computers are not yet capable of making forecasts on this scale through numerical or statistical techniques. An alternative approach is to use successive images to compute a motion vector and use this motion vector to extrapolate the pattern and make forecasts.

Computer-based techniques for extracting motion vectors were found described in scientific literature, and four candidate techniques were programmed. The first two techniques are based on identifying specific clouds or cloud features, finding the matching clouds, and determining the associated displacement. The other two techniques work by overlaying two consecutive images and computing cross-covariance for a variety of trial displacements, with the highest covariance representing the motion vector.

An initial test was made by artificially displacing satellite video images, to determine how well the techniques could specify these displacements. All techniques worked quite well when the cloud patterns were primarily in the center of the data arrays, but only the technique using cross-covariance through logical arithmatic ("binary cross-covariance") performed equally as well when cloud patterns were on the edge of the arrays. Even after pre-processing the input data (smoothing and removing edge-to-edge gradient), the binary cross-covariance was clearly superior to the other three. The relative success of this technique is probably not due to the use of logical arithmatic, but more likely due to use of a smaller array moving inside a larger array in obtaining covariance.

Further tests will be conducted, using series of half-hourly video images, and the goal will be to produce the best forecasts of cloud brightness.

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